All Things Being Equal!

OBJECTIVES

To study equilibrium and understand what happens to the concentration of reactants and products in an equilibrium system.

PROBLEM / QUESTION

What does it mean to have a chemical equilibrium system? What are factors that affect a chemical equilibrium system? What happens to the chemical equilibrium system if you change one of these factors?

PRIOR KNOWLEDGE

You will need to understand a reversible reaction and what it means when a reaction is reversed. You also need to know the collision theory.

SAFETY

No safety issues for Part I and III. Potassium thiocyanate causes irritation to eyes, skin and respiratory tracts. Iron (III) nitrate nonahydrate is a strong oxidizer. Disodium hydrogen phosphate causes irritation to eyes, skin and respiratory tracts.

MATERIALS

Part I: Graph paper
Part II: Dropper bottles of chemicals will be provided at your lab tables, 4 small test tubes and 1 large test tube
Part III: Reaction kit: Red/yellow chips, colorless chips, and reaction paper

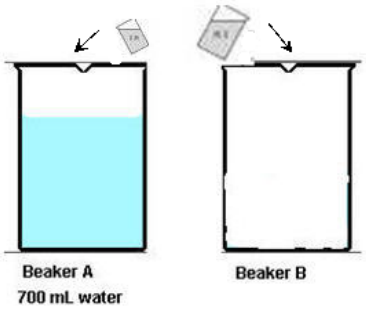
BACKGROUND INFORMATION

When you first learn about chemical reactions, you learn that reactants form products. As such we generally think that in a reaction all of the reactant species break apart and form new product species such that, at the end of a reaction all of the reactants have been used up and only products remain. This, however, is not the case for many reactions. Many reactions do not go just from reactants to products, they can also go from products to reactants. Additionally, many reactions do not go to completion, but rather there are always some reactants and some products present in the reaction mixture. For these types of reactions we talk about "equilibrium systems". Equilibrium systems are everywhere. Understanding how an equilibrium system works and the factors that affect equilibrium systems is very important for understanding a lot of chemistry; how our body maintains a very narrow pH range and how to maximize the desired output of chemical industrial process to name just a couple of examples.

PROCEDURE

Part I: Investigating a simple physical equilibrium system.

Materials: 4 beakers: 100 mL and 50 mL and **two** 1000 mL beakers (A and B)



Read step a-e and make a data table for the activity.

a) Fill beaker according to the picture above.
b) Record the volume of water in the beakers in the data table (cycle 0)
c) Transfer water from beaker A→B and B→A according to the following rules
   - Use the 100 mL beaker to transfer water from A to B;
   - Use the 50 mL beaker transfer water from B to A.
   - Fill the small beakers as full as possible **without tipping the large beakers** in any way.
   - One cycle consists of one A □ B transfer and one B □ A transfer.
   - **For each cycle**, record the volume of water in beakers A and B.
d) Continue cycles and recording the volumes, until the level of water in beakers A and B are unchanging for at least four cycles.

DATA TABLE:(prepare on a separate sheet)

ANALYSIS

A. Graphing

Graph the volume of water (in beakers A and B) versus cycle. Make sure you label both axes and title the graph. Be sure the reader can distinguish between the A and B points on the graph (use different colors or symbols for points). Trace the points to make smooth curves for each plot.

B. Questions

1. What do think is meant by equilibrium?

2. On the graph, circle the points where you believe the reaction has reached equilibrium.

3. What cycle(s) of the experiment did the reaction reach equilibrium? B) How do you know?

B)

4. Compare your ideas about equilibrium with another group (see your teacher for your partner group). Look up the textbook definition of equilibrium and write it here. Does this definition match your definition? Why or why not? With your partner group, look at the graph and determine where the reaction reaches equilibrium. If this position is not the same position you circled for question 2, circle the new point on your graph in a different color and indicate the color here.

5. At equilibrium, is the amount of water in Beaker A equal to the amount of water in Beaker B?

6. Based on the graph what must be the same in order for a reaction to be at equilibrium?

PART II: A macroscopic view of a chemical equilibrium system
INTRODUCTION

An equilibrium system exists where a reversible reaction is taking place when the rates of the forward and reverse reactions are equal. The symbol for reversible reaction is (⇌) and indicates that the reaction can occur in the forward and reverse directions at the same time. During the school year we have studied reversible reactions and now we will study an equilibrium system.

An equilibrium system can be formed in the solution with the following ions:

	Fe^{+3} +	SCN^{-}	$FeSCN^{+2}$
Color: Of ions	light orange	Colorless	Red

The above reaction is a reversible reaction.

1. A) Write the equation for the reaction in the forward direction. B) What are the colors of the reactants and products for this reaction?

A)

B)

2. A) Write the equation for the reaction in the reverse direction. B) What are the colors of the reactants and products for this reaction (in the reverse direction)?

A)

B)

Teacher Check _____

PROCEDURE

1. Fill a **small** test tube with SCN^- (KSCN) solution. In another **small** test tube put in 10 drops of Fe^{+3} ($Fe(NO_3)_3$) solution. Record the color of the solutions and confirm that the colors are the same as listed above.

2. Mix the two solutions together in **LARGE** test tube. Record the color of the solution when the Fe^{+3}, SCN^- and $FeSCN^{+2}$ are all present at the same time.

3. Take this solution and pour equal amounts into three **small** test tubes (label 1, 2, and 3).Test tube 1 is the reference tube and tests will be run on test tubes 2 and 3.

4. To test tube #2 add 4 drops of 0.10 M KSCN (make sure this is the correct solution). Stir and record the results.

b. How does the color of test tube #2 compare to test tube #1?

c. Based on the color of the solution in the test tube, what do you think is happening to the concentration of Fe^{3+}? $FeSCN^{2+}$?Justify your answers.

5. To test tube #3, add 4 drops of 0.10 M Na_2HPO_4, one at time. This compound will react with Fe^{+3} to form $Fe(HPO_4)^{2+}$ (this is the same effect as removing the Fe^{+3} ion from the reaction). Stir and record the results.

b. How does color of test tube #3 compare to test tube #1?

c. Based on the color of the solution in the test tube, do you see a change in the concentration of reactants or products? How do you know?

_____ Teacher check

Part III: A Particulate View of a Chemical Equilibrium System

The purpose of Part III of the activity is to understand what is happening at the particulate level in the reactions in Part II of the activity. If known, an equilibrium constant (K) may be used to determine if a system is at equilibrium or not. The following is the generic formula for writing an equilibrium constant.

$aA + bB \quad cC + dD$ a = coefficients of a balanced equation
A = compounds/elements

$$K = \frac{[C]^c \times [D]^d}{[A]^a \times [B]^b}$$

<u>Materials per group</u>: Reaction chips (10 of two sided chips – red/orange, 10 of the colorless chips), Reaction paper (represents the reaction test tube)

In this reaction Fe^{+3} is represented by an orange chip, SCN^- is represented by a colorless chip, and the product, $FeSCN^{+2}$ is presented by a red chips (other side of the orange chip) and a colorless chip on top of it.

1. From the previous page, rewrite the balanced reaction and colors for each ion.

2. Write the equilibrium expression (K_{eq}) for the reaction.

3. A) Based on your equilibrium constant, which particles (reactants or products) are always in the numerator of the equilibrium expression, K? B) Which particles (reactants or products) are always in the denominator of the equilibrium expression?
   A)

   B)

4. This reaction is at equilibrium when there are 2 Fe^{+3} (orange chips), 6 SCN^- (colorless chips) and 3 $FeSCN^{+2}$ (colorless chip on top of a red chips). On the reaction paper, use the chips to represent this reaction at equilibrium.

5. Fill in the table below with the number of each type of ion in your "test tube."

$[Fe^{+3}]$	$[SCN^{-}]$	$[FeSCN^{+2}]$
Orange Particles	Colorless Particles	Red Particles

6. Look at your reaction vessel. Does this "test tube" contain equal numbers of reactant particles and product particles?

7. Using the equilibrium expression (K_{eq}) and the information in Question #5, calculate the equilibrium constant for this reaction (leave in fraction form – reduced to lowest terms). Do the calculation here.

8. The color of a reaction is determined by which colored particles are most prevalent in the container. (In other words if there are 10 green particles and 8 blue particles in a container, the reaction will look green-blue). If two colors have the same number of particles then the color of the reaction is a mixture of both of them (10 red particles and 10 blue particles will look purple). Based on the ions on the paper, what color would we observe if we had moles of these ions in the same ratio as given by the chips?

9. One stress that can be placed on an equilibrium system is to change the concentration of the reactants or products. Add 4 orange chips and 1colorless chip to your system. At this time do not touch or adjust the products. Now how many of each chip is in the system? Fill in the number on the table for question #10.

10. Based on the chips in your "test tube" now, B) If this new system, is at equilibrium, the ratio of reactants and products should equal the value you found for K earlier (that's why it's called a constant). Calculate the value. C) Is this reaction at equilibrium? How do you know?

$[Fe^{+3}]$	$[SCN^{-}]$	$[FeSCN^{+2}]$
Orange	Colorless	Red
B)		

C)

11. Is the ratio you calculated from question #10 bigger or smaller than the equilibrium constant K (question #7). Use what you know about fractions and decide if you need more reactants or products to reestablish equilibrium.

12. Without removing any ions (chips) from the test tube (paper), reorganize them (make reactants into products or products into reactants) such that the system will be at equilibrium. Use the space below to complete any necessary calculations.

13. Once you have successfully reestablished equilibrium, A) Fill in the chart below B) Calculate your equilibrium constant to be sure. C) What did you need to do to change your model so that it showed a system at equilibrium?

$[Fe^{+3}]$	$[SCN^{-}]$	$[FeSCN^{+2}]$
Orange	Colorless	Red
B)		

C)

14. Based on the information from Question #8, what is the color of the system now?

15. Generalize your results: Adding reactants to the system resulted in an increase/decrease (circle one) in the concentration of products.

Removing particles from the equilibrium:

16. To the system in Question #13, remove 2 orange particles and 4 colorless particles (don't touch any of the product particles). A) Now in the table fill in how many of each particle is left. B) Calculate the ratio and compare it to your equilibrium constant K. C) Is the system at equilibrium?

$[Fe^{+3}]$	$[SCN^{-}]$	$[FeSCN^{+2}]$
Orange	Colorless	Red
B)		

C)

17. Is the ratio you calculated from question #16 bigger or smaller than the equilibrium constant K (question #7). Use what you know about fractions and decide if you need more reactants or products to reestablish equilibrium.

18. Without removing any ions (chips) from the beaker (paper), reorganize them such that the system will be at equilibrium (make reactants into products or products into reactants). Use the space below for any necessary calculations.

19. Once you have successfully reestablished equilibrium, A) Fill in the table. B) Calculate your equilibrium constant to be sure. C) What did you need to do to change your model so that it showed a system at equilibrium?

$[Fe^{+3}]$	$[SCN^{-}]$	$[FeSCN^{+2}]$
Orange	Colorless	Red
B)		

C)

20. What color is the system? Why?

21. Generalize your results: Removing the reactants from the system resulted in an increase/decrease (circle one) in the concentration of products.

FOLLOW-UP QUESTIONS

1. A student states that an equilibrium system is when the amounts of reactants and products are equal. Why isn't this comment correct? What would you tell the student to correct their error? What is the factor that is the "same"?

2. A) For Part III, when the reaction is at equilibrium, what is the color of the reaction (remember you had 3 different equilibrium conditions for this reaction, be sure to list the colors for each equilibrium). B) How is it possible for the same reaction to be at equilibrium yet be different colors?

A)

B)

3. In parts II and III of this activity we examined something called Le Chatelier's principle which states that when a stress is applied to an equilibrium system, that system shifts to offset the stress.

   A. What was the stress applied in Part II step 4 and Part III step 9?

   B. What kind of shift did that cause in the equilibrium system?

   C. Use collision theory to explain why this stress would cause the equilibrium system to shift this way.

   D. What was the stress applied in Part II step 5 and Part III step 16?

   E. Use collision theory to explain why this stress caused the equilibrium system to shift.

   F. Can you think of any other stress you could apply to this equilibrium system?

   G. What effect do you predict it would have on the equilibrium system?

REFERENCES

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